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METHOD AND DEVICE FOR CALIBRATING SENSORS IN A
MOTOR VEHICLE

Background Information

The use of a plurality of sensors in motor vehicles for detecting the vehicle environment is known. Preferably, the 5 use of image sensor systems, infrared sensors, ultrasound sensors and radar sensors is planned. For example, radar sensors are used to detect the vehicle environment in the direction of travel. This makes it possible to regulate the speed of the vehicle, the road speed being adapted to slower 10 moving vehicles when the radar sensor detects them in the heading range of the motor vehicle.

For the sensors to function properly, they must be aligned with respect to the motor vehicle and the vehicle environment. 15 To this end, the sensors are calibrated in an environment similar to a laboratory after they have been installed in the vehicle. For example, a method for aligning the beam pattern of a radar sensor is known from German Patent DE 197 07 590 C2. A calibration object having the reference 20 features for determining the calibration data is used for calibration. References to the calibration of additional sensors are lacking here.

Advantages of the Invention

25 The method described below has the advantage that through the use of a common calibration object for various sensor types, the sensors are aligned on a coordinate system. This makes it

possible for the data of the sensors calibrated in this manner to be used jointly without discrepancies in the measurements. This is advantageous in particular for the use of a radar sensor and an image sensor system. For example, it is possible to combine the data detected by a radar sensor concerning a vehicle traveling in front with the data of the image sensor system, which has identified the same vehicle as an image object. It is possible to use this for a redundant, error-reducing analysis of the data of both sensors.

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Advantageously, the described method and the device reduce the time and effort required for calibrating sensors that are situated in a motor vehicle, for example. Preferably, it is possible to perform the calibration in one operation during production or when a motor vehicle visits a workshop after the installation of a radar sensor and an image sensor system. The use of a single calibration object may advantageously make it possible to determine the calibration data of both sensors simultaneously, i.e., the calibration data is determined in one operation in a close temporal relationship. This results in a reduction of the time required to calibrate sensors during the production or repair of a motor vehicle. This is associated with a reduction in the production or repair costs.

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In an advantageous manner, the calibration data is preferably used further by downstream systems. The calibration data may be stored and/or analyzed and/or displayed and/or transmitted and/or further processed. Furthermore, the sensors themselves are able to use the calibration data further in an advantageous manner. For example, it is possible in a radar sensor to use the calibration data to correct the discrepancy of the sensor axis in relation to the direction of the vehicle longitudinal axis. In an image sensor system, it is possible to use the calibration data to correct the image data automatically. The extrinsic parameters, preferably the

geometrical installation position and/or the direction of the sensor axis, and/or intrinsic parameters, preferably the camera's principal point and/or the camera constant and/or the distortion, are determined here as calibration data.

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In an advantageous manner in particular, it is possible to use at least one additional sensor as a reference for calibrating a sensor. The calibration data of the sensor is formed from the data of the detected calibration object and additionally 10 from the measured data of at least one additional sensor, this reference sensor using the same calibration object. In a motor vehicle having a radar sensor and an image sensor system, it is possible, for example, to use the data of the image sensor system as a reference for determining the calibration data of 15 the radar sensor. In an advantageous manner in particular, it is possible, for example, during a repair of the radar sensor, with a recalibration being necessary, to form the calibration data of the radar sensor from the measured data of the image sensor system and the data of the calibration object detected 20 by the radar sensor. This advantageously results in an increase in the measuring accuracy of the radar sensor.

Of particular advantage is the use of a single calibration object, which has at least one reference feature for each 25 sensor for the at least two sensors, the at least two sensors being of a different sensor type. The combination of the reference features into one calibration object for calibrating at least two sensors of a different sensor type substantially facilitates the calibration, for example, in the production of 30 a motor vehicle because it is now only necessary to align the motor vehicle to one calibration object.

In addition, the combination of the reference features into one calibration object has the advantage that the calibration 35 object may be designed in such a way that the physical

position of the reference features in relation to each other is known. In an advantageous manner, this forms the basis for using the measured data of a sensor as a reference for another sensor.

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In an advantageous manner, a triple mirror is used as a reference feature for the radar sensor. Triple mirrors are distinguished by three reflection surfaces, which are perpendicular in relation to each other, which make a parallel reflection of the incident radar beam possible, the radar beam being reflected in a wide angular range parallel to the incident beam with reference to the reflection surfaces.

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In one variation of the calibration object, calibration marks are placed on the triple mirror. This advantageously makes it possible to use the triple mirror as a reference feature for the radar sensor and the image sensor system. The use of this device makes any additional reference features for the image sensor system unnecessary. Furthermore, this system makes the physical position of the reference features known for the radar sensor and the image sensor system. It is thus possible to use the radar sensor as a reference for the image sensor system and the image sensor system as a reference for the radar sensor.

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Additional advantages are derived from the following description of exemplary embodiments with reference to the figures, and from the dependent claims.

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Drawing

The present invention will be explained in greater detail below with reference to the embodiments shown in the drawing in which:

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Figure 1 shows a general drawing of the device for calibrating sensors in the motor vehicle, with reference to which the method is also described,
5 Figure 2 shows a flowchart of the method for calibrating sensors,
Figure 3 shows a block diagram of the device for calibrating sensors.

Description of Exemplary Embodiments

10 In a general drawing, Figure 1 shows a preferred exemplary embodiment for calibrating sensors 14, 16. On and/or in a motor vehicle 12 are located a radar sensor 14, which is preferably attached to the bumper, and an image sensor system 16, which is preferably situated in the vehicle interior. Both
15 sensors 14, 16 have a detection range 15, 17, each of which is aligned in the direction of vehicle longitudinal axis 11 in the direction of travel of motor vehicle 12. In the preferred exemplary embodiment, the direction of detection ranges 15, 17
20 is determined by the sensor axes. In radar sensor 14, the direction of maximum sensitivity of radar sensor 14 determines the sensor axis while in image sensor system 16, the optical axis is the sensor axis. In the preferred exemplary embodiment, detection range 15 of radar sensor 14 coincides
25 with detection range 17 of image sensor system 16. In the preferred exemplary embodiment, image sensor system 16 includes one image sensor whose design is based, for example, on CMOS or CCD technology. Motor vehicle 12 is aligned in front of a calibration object 10 in such a way that radar
30 sensor 14 and image sensor system 16 detect reference features 18, 20 on calibration object 10. In the preferred exemplary embodiment, it is sufficient that radar sensor 14 detects reference feature 18 and image sensor system 16 detects reference feature 20. Calibration object 10 is a flat or
35 three-dimensional system of reference features 18, 20, which

are connected by a mechanical mounting device. In the preferred exemplary embodiment, both reference features 18, 20 are mounted on a flat wall, which is used as a mounting device. Reference features 18, 20 are designed in such a way 5 that they are always detectable by radar sensor 14 and image sensor system 16. Reference feature 18, which is detected by radar sensor 14, has characteristic properties. In the preferred exemplary embodiment, radar sensor 14 is a radar receiver, which is combined with a transmitter for radar 10 radiation. Reference feature 18 must be designed in such a way that it reflects the incident radar beam back to radar sensor 14. In the preferred exemplary embodiment, it is a triple mirror. Reference feature 20, which is detected by image sensor system 16, also has particular properties. Preferably, 15 reference feature 20 has a high contrast and/or a reflective surface and/or it has a particular shape, such as a circular or rectangular shape, for example. In order to calibrate image sensor system 16, one to any desired number of reference features 20 is necessary, preferably between ten and 50 20 reference features 20 being used. In the preferred exemplary embodiment, for example, 40 reference features 20 are used to determine the calibration data of image sensor system 16, their physical location being known. This makes a redundant determination of the calibration data for image sensor system 25 16 possible.

Figure 2 shows a flowchart of the method for calibrating sensors 14, 16. In block 22, sensors 14, 16 are aligned in relation to calibration object 10. In the preferred exemplary 30 embodiment, this is done by aligning motor vehicle 12, on which radar sensor 14 and image sensor system 16 are located, in relation to calibration object 10. Alternatively, it is possible to align calibration object 10 in relation to motor vehicle 12. In block 24, reference features 18, 20 of 35 calibration object 10 are detected by sensors 14, 16. Block 26

is used to determine the calibration data for radar sensor 14 and image sensor system 16 from the data determined of detected calibration object 10. The calibration data are determined simultaneously, i.e., the calibration data are 5 determined in one operation in a close temporal relationship. Preferably, the direction of the sensor axis in relation to vehicle longitudinal axis 11 and/or the intensity of the radar beam are determined as calibration data in radar sensor 14. To determine the calibration data, known reference feature 20 is 10 recorded as an image in block 24 in image sensor system 16 and the individual parameters of the calibration data are calculated in a computation of adjustment in subsequent block 26. In the preferred exemplary embodiment, extrinsic parameters, preferably the geometric installation position 15 and/or the direction of the sensor axis, and/or intrinsic parameters, preferably the camera's principal point and/or the camera constant and/or the distortion, are determined as calibration data in a single image sensor system 16. The determined calibration data is further processed in block 28. 20 The calibration data may preferably be stored and/or analyzed and/or displayed and/or transmitted and/or further processed by at least one downstream system 34. In addition, the calibration data is further used directly for calibration in participating sensors 14, 16. In doing so, it is possible to 25 process and/or store the calibration data. In the preferred exemplary embodiment, image sensor system 16 uses the calibration data for the automatic correction of the images in the operation of image sensor system 16. In the preferred exemplary embodiment, radar sensor 14 uses the calibration 30 data for the automatic correction of the deviation of the sensor axis in relation to the direction of vehicle longitudinal axis 11. As an alternative, it is possible to display the determined calibration data and thus, for example, to make it possible for an automotive mechanic to use the 35 calibration data for the mechanical adjustment of radar sensor

14. This procedure is conceivable during the manufacture or
the repair of a motor vehicle 12.

Figure 3 shows a block diagram of the device for calibrating
5 sensors 14, 16. In the preferred exemplary embodiment, a radar
sensor 14 and an image sensor system 16 detect a calibration
object 10. The calibration data for the two sensors 14, 16 is
determined in two analyzing units 30, 32. The calibration data
is further utilized in a downstream system 34.

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The method described above and the device for calibrating
sensors 14, 16 are not limited to radar sensors 14 and image
sensor systems 16 in motor vehicles 12. Instead, sensors 14,
15 16 may be calibrated in systems outside of motor vehicle 12,
sensors 14, 16 being characterized by a three-dimensional
detection range 15, 17 and preferably having one sensor axis.
In particular, the described method and the device may be used
in radar sensors 14 and/or image sensor systems 16 and/or
light sensors and/or ultrasound sensors and/or LIDAR sensors.

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At the same time the method may also be implemented with more
than two sensors 14, 16. With more than two sensors 14, 16,
sensors 14, 16 of the same sensor type using the same
reference features 18, 20 may also be used. Two possible
systems are, for example, at least one radar sensor 14
25 including at least two image sensor systems 16 or at least two
radar sensors 14 including at least one image sensor system
16, sensors 14, 16 preferably being situated in a motor
vehicle 12. If at least two image sensor systems 16 are used,
additional calibration data is determined, which contain the
30 physical position and/or the alignment of the sensor axes of
image sensor systems 16 in relation to each other.

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The alignment of detection ranges 15, 17 of sensors 14, 16 is
discretionary. As in the preferred exemplary embodiment,
detection ranges 15, 17 may include the vehicle environment.

It is also conceivable to align detection ranges 15, 17 into the vehicle interior. Any desired mutual alignment of detection ranges 15, 17 of sensors 14, 16 is possible. In particular, the identical or diametrically opposed alignment of detection ranges 15, 17 is conceivable. Sensors 14, 16 may be situated both within motor vehicle 12 as well as outside of it. For example, it is possible to mount sensors 14, 16 in the interior of the vehicle and/or on the bumper and/or in the luggage compartment and/or in the engine compartment. The only prerequisite for using the device and the method is that calibration object 10 must be adjusted to the installation position and the alignment of detection ranges 15, 17 of sensors 14, 16 by the physical positioning of reference features 18, 20.

A coincidence of detection ranges 15, 17 of sensors 14, 16 is not a necessary prerequisite for implementing the method. In the case of detection ranges 15, 17 of sensors 14, 16 that do not coincide, calibration object 10 must simply be designed in such a way that a detection of necessary reference features 18, 20 is possible in one operation for each individual sensor 14, 16. It is not necessary for each sensor 14, 16 to detect entire calibration object 10 including all reference features 18, 20.

The method is also possible with moving sensors 14, 16 and/or with moving calibration object 10. For example, in the preferred exemplary embodiment, the device is also usable in a moving motor vehicle 12.

In one variation of the described method, a sensor 14, 16 is used as a reference for another sensor 14, 16. For example, the calibration data of radar sensor 14 may be formed as a reference from the measured data of already calibrated image sensor system 16 and the data of calibration object 10

detected by radar sensor 14. The physical position of reference feature 18, which is necessary to determine the calibration data of radar sensor 14, may be determined by image sensor system 16. The physical position of reference 5 feature 18 is determined indirectly by analyzing reference feature 20 using the known physical positioning of reference features 18, 20 in relation to each other.

In another variation of the described method, radar sensor 14 10 is used as a reference for image sensor system 16. Already calibrated radar sensor 14 is used for the range finding. Radar sensor 14 determines the distance of reference feature 18 from radar sensor 14. Image sensor system 16 uses the known physical positioning of reference features 18, 20 and the 15 determined distance of reference feature 18 from radar sensor 14 as a reference for determining the calibration data by analyzing calibration object 10.

As in the preferred exemplary embodiment, the calibration data 20 of sensors 14, 16 may be determined by separate analyzing units 30, 32. As an alternative, it is possible for a single analyzing unit to determine the calibration data. In another variation, the integration of analyzing units 30, 32 with sensors 14, 16 is conceivable.

25 In one variation of the described method, calibration object 10 may be connected directly to motor vehicle 12 by a mechanical link. This establishes the physical position of calibration object 10 in relation to motor vehicle 12.

30 In another variation of the described method, the use of a triple mirror having calibration marks makes it possible to determine the calibration data of radar sensor 14 and of image sensor system 16 directly on the triple mirror because the 35 triple mirror having calibration marks has both a reference

feature 18 for radar sensor 14 and a reference feature 20 for image sensor system 16. This makes it possible to use radar sensor 14 as a reference for image sensor system 16 and image sensor system 16 for radar sensor 14 for determining the
5 calibration data. Moreover, additional reference features 20 may be present for image sensor system 16.

The number of reference features 18, 20 for individual sensors 14, 16 establishes the number of determinable parameters of
10 the calibration data. With more reference features 18, 20 for individual sensors 14, 16, more parameters are determinable, and/or an overdetermination and accordingly an increase in the precision for determining the parameters are possible.

15 The calibration by a single calibration object 10 in which the physical position of reference features 18, 20 is known, makes common use of sensors 14, 16 possible because the calibration data refers to a common coordinate system. In particular, when a radar sensor 14 and an image sensor system 16 are used in a
20 motor vehicle 12 as in the preferred exemplary embodiment, the measured data of radar sensor 14 may be combined with the data of image sensor system 16. In particular, vehicles traveling in front may be detected by both sensors 14, 16 and the measured data may be used for redundant error-reducing
25 analyses.